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STRUCTURAL DESCRIPTION METHOD OF THE SUSTAINABLE SOCIETY SCENARIOS FOR SCENARIO DESIGN

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ABSTRACT
Today, many scenarios are described for envisioning sustainable society such as the IPCC's Emissions Scenarios. These scenarios often employ simulators to provide a basis for their descriptions. However, existing scenarios do not explicitly describe the relationship between scenario document and simulators, *e.g.* its simulation conditions. This spoils reusability of scenarios. We propose a scenario design methodology to describe sustainable society scenario efficiently and effectively. We are developing Sustainable Society Scenario (3S) Simulator to support scenario design process. This paper proposes a method for making new scenario variants efficiently by reusing existing scenarios and simulators. In order to realize proposed method, we define a structural description method of scenarios for connecting scenarios with their simulators dynamically and we develop a data managing tools as components of 3S Simulator to modify scenarios by using proposed method. In a case study, scenario structure including simulator is clearly represented and we succeeded in describing new sub scenario easily by reusing existing scenario and simulator.

Keywords: Sustainable Society, Scenario, Simulator, Structural Description

1 INTRODUCTION
Toward the sustainable society, a variety of scenarios have been described, such as the IPCC's Emissions Scenarios [1], the 2050 Japan Low-Carbon Society scenario [2], and the IEA's World Energy Outlook 2004 [3]. A scenario is a story that logically derives the future from the present situation [4] in order to discuss long-term policies and strategies. In other words, since describing a scenario is a process to generate an artifact (*viz.*, scenario) that has not existed yet, the scenario for the sustainable society (or the sustainable society scenario) is a good target of design.

Those scenarios often include computer simulations to predict and verify their future visions. However, current forms of the scenarios have two problems. First, logical structures of scenarios are unclear, this cause difficulties in understanding the basis of the future visions in scenarios. Second, simulators used in scenarios are difficult to reuse. We cannot easily create a new scenario by reusing existing scenarios or their simulators.

The objective of this study is to propose a design methodology of scenarios toward the sustainable society by developing Sustainable Society Scenario (3S) Simulator (see Section 2). Especially, this paper proposes a scenario description method for clarifying the logical structure of a scenario. And we also propose a dynamic connection of scenarios and simulators in order to support describing new scenarios by reusing existing scenarios and their simulators.

2 DESIGHNING SUSTAINABLE SOCIETY SCENARIOS
Alcamo [5] showed the SAS (Story And Simulation) approach as a general framework for describing and analyzing the sustainable society scenarios. In SAS approach, a scenario is composed of two important elements; *viz.* storyline and simulator. A storyline is a narrative description of a scenario, which highlights its main features and the relationships between the scenario's driving forces and its main features [5]. Simulator is mainly used to quantify the storyline and provide a basis for it. In fact, many of the scenarios including IPCC's scenario are described using SAS approach. IPCC described their scenario using AIM (Asia pacific Integrated Model) [6].

However, existing scenarios have problems. First, their logical structures are difficult to understand. This causes difficulties in distinguishing the hypotheses of the scenario from scientific or historical facts. Second, existing scenarios and simulators are difficult to reuse. The relationship between the storyline and simulation is unclear. Simulators used in the scenario and their inputs and outputs are not explicitly described in scenario document. How these inputs are determined or how these outputs are used to derive the conclusion is unclear. We cannot easily modify, verify or analyze existing scenarios. Third, there is no computational support method of scenario description. It is difficult for us to describe scenarios efficiently.

In order to solve the problems pointed above, we are developing 3S (Sustainable Society Scenario) Simulator [7]. We have proposed the following six subjects for 3S Simulator:

1. Structuralizing scenarios for clarifying the logical structure of the scenario documents by defining ontology of scenarios.
2. Archiving scenarios and simulators used in scenarios.
3. Supporting verification and modification of scenarios by connecting a scenario with simulators dynamically.
4. Analyzing scenarios like structure analysis, what-if analysis, or sensitivity analysis.
5. Supporting design of new scenarios including forecasting and backcasting process by using archived scenarios and their simulators.
6. Comparing and combining different scenarios.

Figure 1 **Error! Reference source not found.**shows the architecture of 3S Simulator. In order to implement the subjects above, we develop the following five components in 3S Simulator:

- Scenario Description Support System: supports describing new or existing scenarios structurally.
- Scenario Archives: archives structuralized scenarios and simulators used in the scenarios.
- Scenario Analysis Tool: analyzes the logical structure of a described scenario and modifies and verifies existing scenarios with their simulators by what-if and sensitivity analyses.
- Scenario Design Support System: supports designing new scenarios using Scenario Archives and other components.
- Data Mediator: exchanges data among simulators to execute simulation.

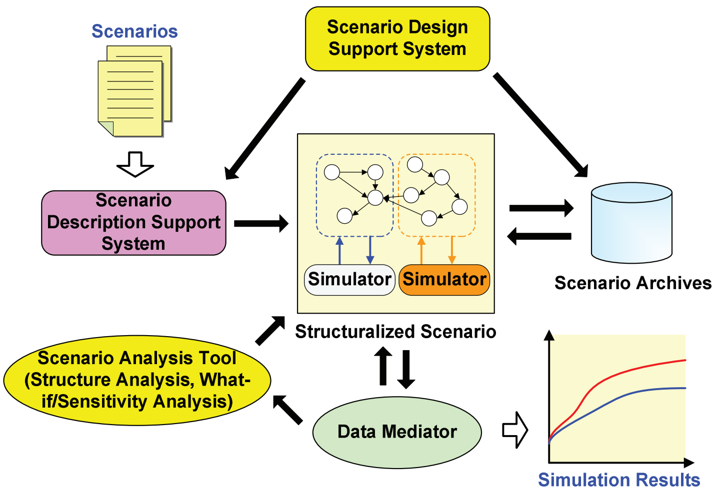

Figure 1. The architecture of 3S Simulator

This paper implements subjects 1 and 3 in order to support scenario description by reusing existing scenarios and simulators efficiently. First, we propose a structural description method of scenario. This method explicitly describes the logical structure of storylines in the way that computer can use. Second, we propose a scenario description method, which enables scenario writers to create new scenarios easily by changing hypotheses of an existing scenario and by executing new simulation based on changed hypotheses.

3 STRUCTURAL SCENARIO DESCRIPTION

3.1 Approach

In order to implement subject 1, we have proposed a structural description method of scenarios as an explicit description method of scenario structure. To comprehend scenarios from macroscopic and microscopic viewpoints, we defined the following four levels [7]:

1. Scenario Level: expresses the structure of blocks of the story of a scenario (sub scenarios)
2. Expression Level: expresses the semantic structure of clauses in a sub scenario
3. Word Level: expresses the meanings of words or phrases included in a clause
4. Data Level: expresses an interface between a scenario document, simulators, and their parameters

We represent a scenario structure as a directed graph composed of nodes and links at each of the four levels. A node expresses an element of a scenario such as a scenario, a clause and a simulator. A link expresses the relation between the nodes such as causality and equal. We define basic types (ontology) of nodes and links for representing the structure of scenarios. In addition to these four levels, links between Expression and Data Level are defined to express the relationship between scenario documents and simulators. This paper focuses mainly on Data Level and the following sections summarize Scenario and Expression Levels since we develop Data Level based on these two levels.
To implement efficient reusing method of existing scenarios and simulators, we propose a dynamic connection of scenarios and simulators. It enables scenario writers to execute a simulation simultaneously with writing scenario documents. Scenario writers can create a new scenario by changing the hypotheses of an existing scenario, executing new simulation based on changed hypotheses, and deriving a new conclusion referring new simulation result. To execute simulation dynamically, we need to manage the input and output parameters of simulators. Data Level nodes pointed above indicate these parameters in the scenario document. Simulator database manages simulators and their input and output parameters. Data Manager translates inputs and outputs in Data Level nodes into the format that simulator program can understand. How this simulation management system works is written in Section 4.

3.2 Scenario Level

Table 1 summarizes the ontology of Scenario Level [8]. We defined two kinds of nodes and four kinds of links for Scenario Level. In this level, a node represents a block of the story of a scenario. A "scenario" node represents a block of a story for a certain theme and includes one or more conclusions about it. A "scenario_component" node represents a part of "scenario" node like a certain block of a scenario text. We define six types for the "scenario_component" node according to scenario contents; *viz.*, background, problem, hypothesis, simulation, discussion, and conclusion. Practically, an individual "scenario_component" node corresponds to a paragraph. Links of Scenario Level is roughly divided to two kind; the one, "consist_of" and "part_of", represents hierarchical structure and the other, "refer" and "compare", represents relations between different scenario hierarchies.

Table 1. The ontology of Scenario Level [8]

Type		Definition
Node	scenario	A description regarding a certain topic. And this node shall include its conclusion.
	scenario_component	A part of a "scenario" node. This node consists of clauses.
Link	consist_of(*A*,*B*)	A "scenario" node *A* includes a "scenario" node *B* as its constituent element.
	part_of(*A*,*B*)	A "scenario" node *A* includes a "scenario_component" node *B* as its constituent element.
	compare(*A*,*B*)	Node *A* is compared with node *B*.
	refer(*A*,*B*)	Node *A* refers to node *B*.

3.3 Expression Level

Expression Level describes the semantic structure of clauses in a scenario [8]. Table 2 summarizes the ontology of this level. In six node types, "fact," "hypothesis," "literature," and "derived_fact" are defined to clarify the rationale of a scenario. Rationale of scenario is the description that indicates the reasons and the reasoning processes of storyline. A "derived_fact" node is always deduced from "hypothesis" nodes or other "derived_fact" nodes by "causality" links. A "causality" link represents the logical derivation of the storyline. The truth-value of a "derived_fact" node is same as that of nodes deduced from. When a scenario contains a simulation, some of the conditions of the simulation are explained or decided in the rationale of the scenario; in "fact," "hypothesis," "literature," and "derived_fact" nodes. "Conclusion" node terminates the logical structure of the scenario; therefore, this node is derived from the rationale of the scenario by "causality" or "logical_jump." Although "problem" nodes do not constitute the rationale of a scenario, they specify the topics of the scenario. The content of the scenario should reflect the content of included "problem" nodes.

Table 2. The ontology of Expression Level [8]

Type		Definition
Node	problem	A motive for creating a scenario, or a problem to be addressed in a scenario.
	conclusion	A conclusion of a scenario, which is derived by "causality" or "logical_jump" links.
	literature	A report, an article, a book, another scenario, and other literature referred in a scenario.
	fact	A historical or scientific fact.
	hypothesis	A premise of a hypothesis introduced to a scenario.
	derived_fact	A consequence deduced from hypotheses or other derived_facts in a scenario by "causality" links.
Link	paradox(*A*,*B*)	The content of node *A* is inconsistent with that of node *B*.
	causality(*A*,*B*)	Node *B* is logically deduced from node *A*.
	logical_jump(*A*,*B*)	Node *B* is derived from node *A* with a leap of logic.
	equal(*A*,*B*)	The content of node *A* is equal to that of node *B*.
	compare(*A*,*B*)	Node *A* is compared with node *B*.
	detail(*A*,*B*)	Node *B* is a detailed description of node *A*.
	refer(*A*,*B*)	Node *A* refers to node *B*.

3.4 Data Level

This paper proposes Data Level description that connects a scenario with simulators. Table 3 summarizes the ontology of this level and Figure 2 illustrates the way Data, Expression, and Scenario Level nodes and links connects scenario with simulator. In this ontology, a simulation is expressed by a "scenario_component" node of which "type" is "simulation". Each simulation consists of a "simulator" node, an input "dataset" node, and an output "dataset" node. A "simulator" node represents a simulator used in a scenario. The "dataset" nodes are connected by "input" or "output" link to a "simulator" node in order to express the I/O relations. A "datum" node indicates an individual parameter in an input or an output.

Table 3. The ontology of Data Level

Type		Definition
Node	dataset	A group of datum representing a set of inputs or outputs of a simulator.
	datum	Each of input data or output data of a simulator. The attributes of "datum" are "label," "value," and "unit."
	simulator	A simulator used in a scenario. This node retains the ID number of a simulator stored in Simulator Database as an attribute.
Link	input(*A*,*B*)	Input data from node *A* (dataset) to *B* (simulator).
	output(*A*,*B*)	Output data from node *A* (simulator) from *B* (dataset).

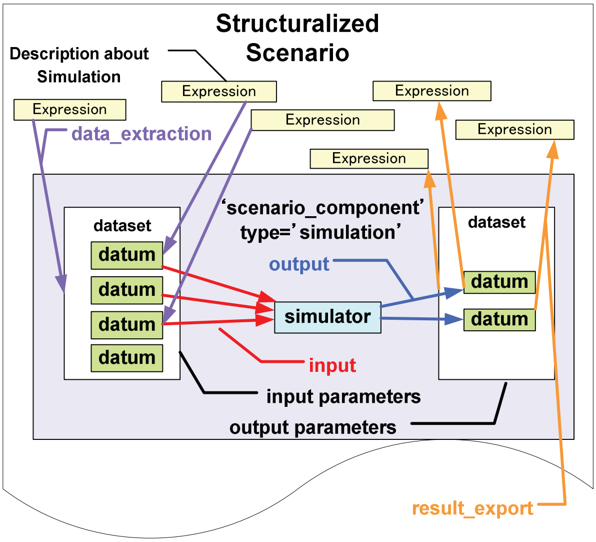

Figure 2. The structure represented by combining Expression and Data Levels

3.5 **Relation between Expression and Data Levels**

In addition to Data Level, in order to represent the relation between the simulation and the context of the scenario document, we define the relation between Expression and Data Levels. Table 4 summarizes these links. A "data_extraction" link connects an Expression Level node that discusses an input parameter to input "dataset" node. A "result_export" link connects an output "dataset" node to an Expression Level node that discusses the simulation result (see Figure 2).

Table 4. Links between Expression and Data Level

Type	Definition
data_extraction (*A*,*B*)	Extract data included in node *A* (Expression Level node) to node *B* (dataset)
result_export (*A*,*B*)	Export data contained in node *A* (dataset) to node *B* (Expression Level node).

4 IMPLEMENTATION

4.1 **Scenario Description Support System**

In the proposed method, scenario ontology (*i.e.*, nodes and links) is expressed as the XML (eXtensible Markup Language) [9] tags. When we structuralize scenarios, we insert XML tags into the original scenario text. In order to support the structuralizing of scenario and understanding scenario structure, we have developed "Scenario Description Support System" as a component of 3S Simulator. Scenarios are structuralized in this system and handled in other components of 3S Simulator. Figure 3 illustrates the architecture of the system. This system consists of three components; "Scenario Structuralizing Support Tool," "Scenario Visualization Tool," and "Data Manager." "Scenario Visualization Tool" transforms structuralized scenario into various visualized forms. Logical Structure Graph represents the graph structure based on the nodes and links. This graph supports users to understand the structure of the scenario. The HTML document outputs colored scenario texts that indicate the node types and images included in the original scenario. This helps users to grasp the relationship between the original scenario text and its tagged text. Elements list indicates the number of nodes and links according to their types at each level.

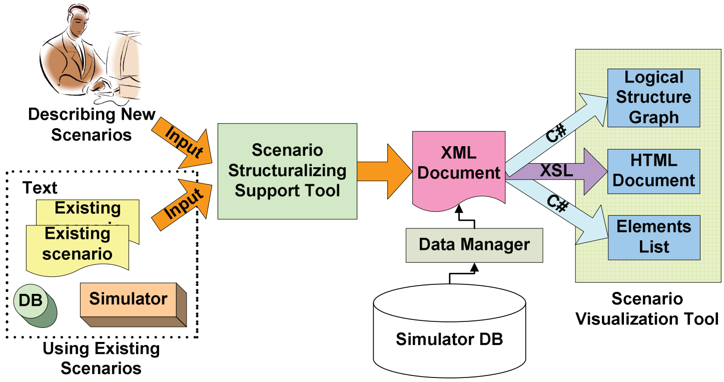

Figure 3. The architecture of Scenario Description Support System

4.2 Connection of scenarios and simulators

In order to represent relation between scenarios and simulators, we added data managing tools into Scenario Description Support System, which connect scenarios with simulators dynamically; *viz.,* "Simulator Database" and "Data Manager." Data Manager extracts input parameters from Data Level nodes in a structuralized scenario, transforms them into the data format each simulator can understand, and returns a set of data and a graph of the simulation result. These tools support describing a new sub scenario by changing the condition of the simulation in the existing scenario.

Simulator Database archives simulators and provides information about them for Data Manager. Simulator Database contains not only simulator programs but also information about simulators, including name of a simulator, author of the simulator, definitions of its input or output parameters, path to the simulator. The contents of a "simulator" node and a "dataset" node are based on the information registered in Simulator Database.

Data Manager works with Simulator Database. The way Data Manager and Simulator Database work is summarized in Figure 4. Execute a simulation on Scenario Description Support System, the user need to insert a "simulator" node at first. Data Manager automatically finds out the "simulator" node, and indicates its input parameters, referring Simulator Database. The user can edit input parameter values in Data Manager and these changes are reflected into the contents of the "dataset" node in the scenario. When all parameter values are decided, Data Manager extracts the contents of input "dataset" and translates them into the data format the simulator can understand. After the simulation, Data Manager inserts a "dataset" node containing the simulation result or graphs that indicates the simulation result into the structuralized scenario. Users manually make "data_extraction" links and "result_export" links to clarify the relation between the scenario document and the simulation.

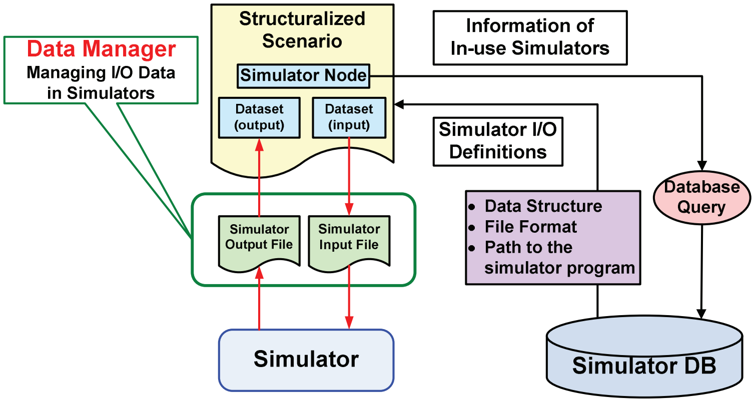

Figure 4. Connection of scenarios and simulators via Data Manager

5 CASE STUDY

5.1 Overview

In order to confirm the effectiveness of proposed method, we analyzed the HEV (Hybrid Electric Vehicle) Diffusion Scenario [10], which prospects the diffusion patterns of HEV in Japan caused by different patterns of subsidy and technological advancement of HEV. This scenario uses HEV diffusion simulator [10], which combines a product diffusion model and consumer preference model. Two people in our study group structuralized the scenario using Scenario Structuralizing Support Tool and reviewed the structure with Scenario Visualization Tool. Therefore, this is the case that an existing scenario is structuralized in Figure 3.

5.2 Scenario Level

We structuralized this scenario in Scenario Level at first. Figure 5***Error! Reference source not found.*** describes the logical structure graph of the scenario in Scenario Level. Scenario Level is defined for expressing the hierarchical structure of a scenario. “Scenario” nodes and “consist_of” links between them clearly describe the hierarchical structure of this scenario in logical structure graph. The “scenario” node in the top of the graph represents the whole HEV Diffusion Scenario. This scenario consists of two sub scenarios, “Base case” and “Scenario cases.” These sub scenarios are compared; “compare” link between these two “scenario” nodes represents this. The sub scenario “Scenario cases” consist of three sub-sub scenarios of HEV Diffusion Scenario; “Subsidy scenario (1),” “Subsidy scenario (2),” and “Technological advancement scenario.” These sub scenarios contain individual simulations, which are based on different simulation conditions on the amount of subsidies and the improvement of gasoline mileage. Common settings between “Base case” and other sub-sub scenarios are written in “scenario_component” nodes, which directly connected to “HEV Diffusion Scenario” node. The conclusion of the scenario as a whole is also connected to “HEV Diffusion Scenario” node and the conclusion node refers to all of the simulation results.

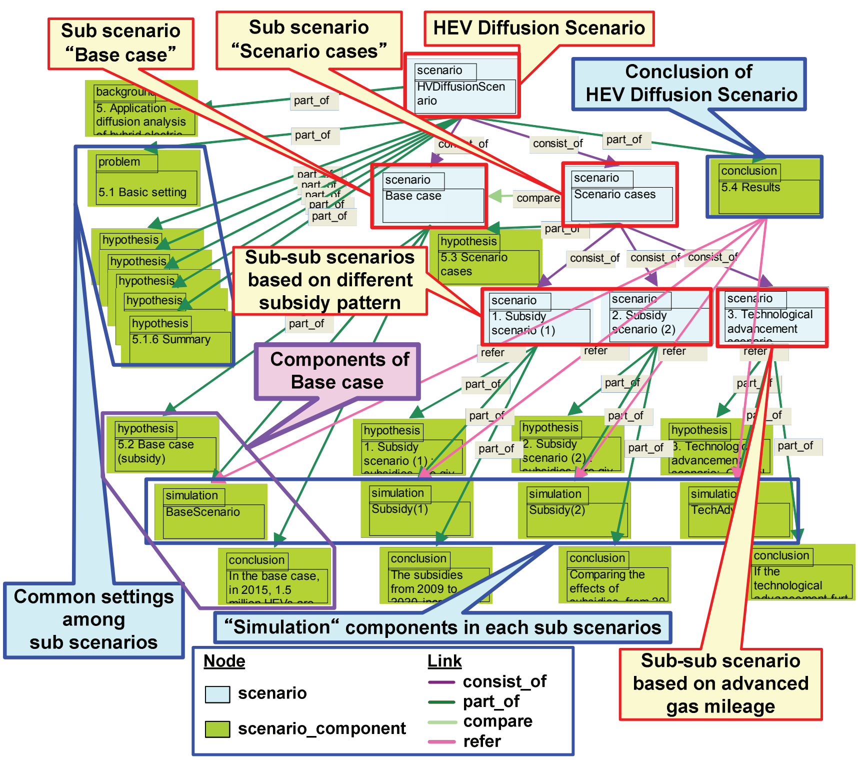

Figure 5. The structure in Scenario Level

5.3 Expression and Data Levels

In Expression and Data Level analysis, we re-execute the simulation as the author of this scenario did. After structuralizing in Expression Level, we manually insert "simulator" nodes in each "simulation" components and set their inputs using Data Manager. And we link the structuralized scenario document with these "dataset" nodes by "data_extraction" and "result_export" links.

As an example of the analysis, Figure 6**Error! Reference source not found.** illustrates the structure of "Base case" sub scenario in Expression Level and Data Level. It is difficult to see Figure 6 in detail, therefore, we discuss overall structure of Figure 6 here. As shown in Figure 5, this sub scenario comprises three "scenario_component" nodes; "hypothesis," "simulation," and "conclusion". Among them, Block A in Figure 6 indicates "simulation" of "Base case." The structure in Figure 6 is divided into two blocks. Block B discusses mainly simulation conditions; therefore, they are the rationale of this scenario. Nodes in Block C represent motivation of the scenario, definition of the problems and backgrounds. The simulation conditions in block B result in parameter values of the simulation. In block B, block D is a set of "hypothesis" components directly connected to the node of this sub scenario in order to decide unique parameters in this sub scenario.

"Data_extraction" links connect the conditions in scenario texts to the input dataset, however not all parameters of the simulation is described in the scenario text. Block E represents the derived result of simulation in the form of figures and tables. Moreover, Block F represents the conclusion of this sub scenario by summarizing the simulation results. In this way, the structural graph in Figure 6 explicitly indicates the way the simulation is executed and its conditions. Therefore, this graph is useful for understanding the sub scenario and finding out the points to be modified for executing another simulation with slightly different conditions.

5.4 Creating a New Scenario Variant

By using Data Manager and Simulator Database, we describe a new sub scenario named "Oil Price Soaring Scenario" by reusing the HEV diffusion simulator. This scenario is intended to examine the effect of the increase of energy price to the consumer's preference and to the diffusion of HEV. Block a in Figure 7 represents Oil Price Soaring Scenario. In order to make this scenario, we decided that the value of "gasoline expense" parameter in 2050 increases up to five times that of 2007 linearly, referring the IEA's assumption [3]. Block b in Figure 7 represents this newly added condition. Since other parameters are set to be the same as the base case, we reused these parameters by using Data Manager; "data_extraction" links from nodes that indicates common conditions illustrates this.

Figure 8 illustrates the simulation result, which is, included in the scenario description. Based on this result, we concluded that increasing energy price will cause faster diffusion of HEV. In this way, we succeeded in making a new scenario variant by changing simulation conditions. Proposed ontology, Data Manager, and Simulator Database supported this process by managing simulation conditions and results.

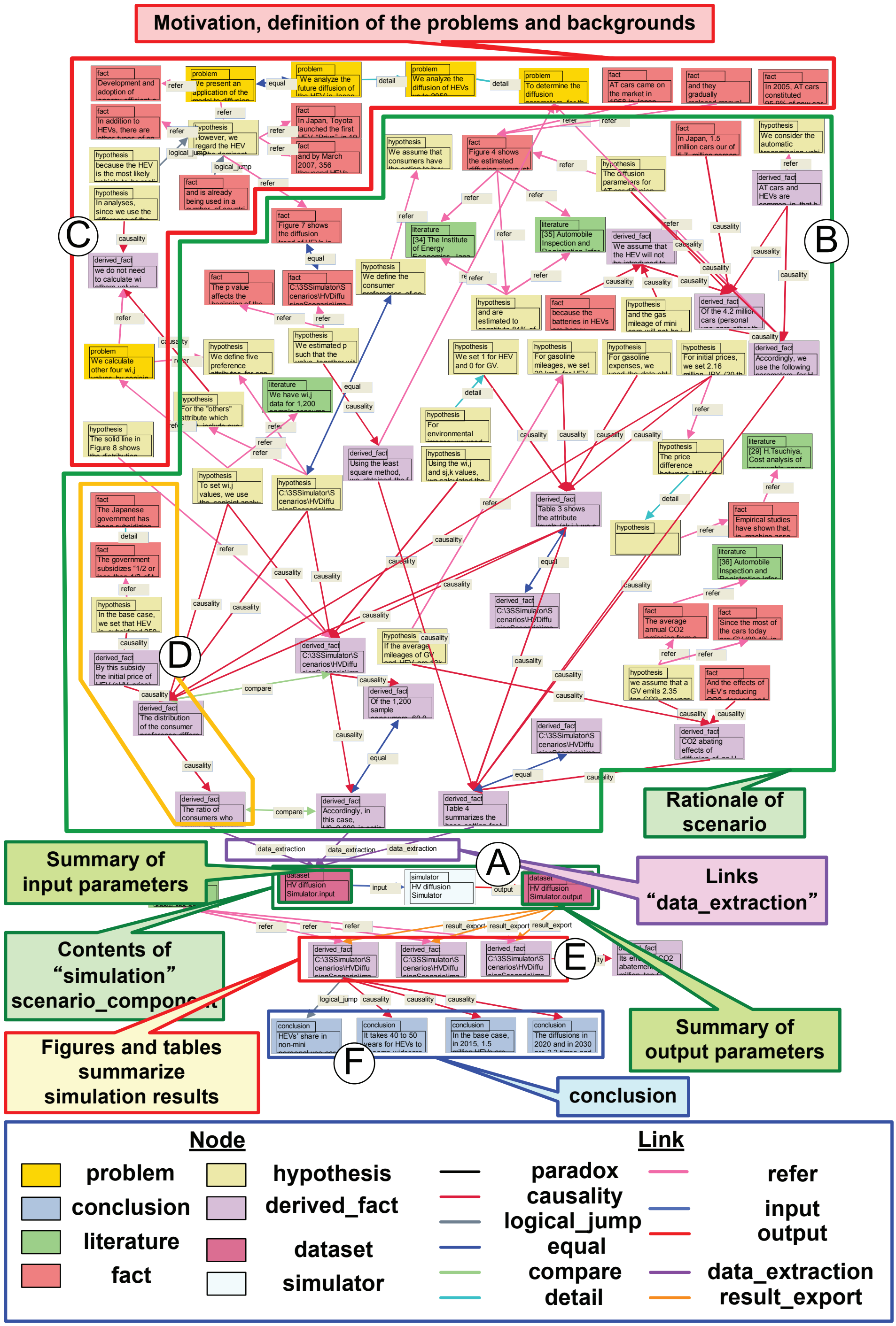

Figure 6. The structure of "Base case (subsidy)" in Expression Level and Data Level

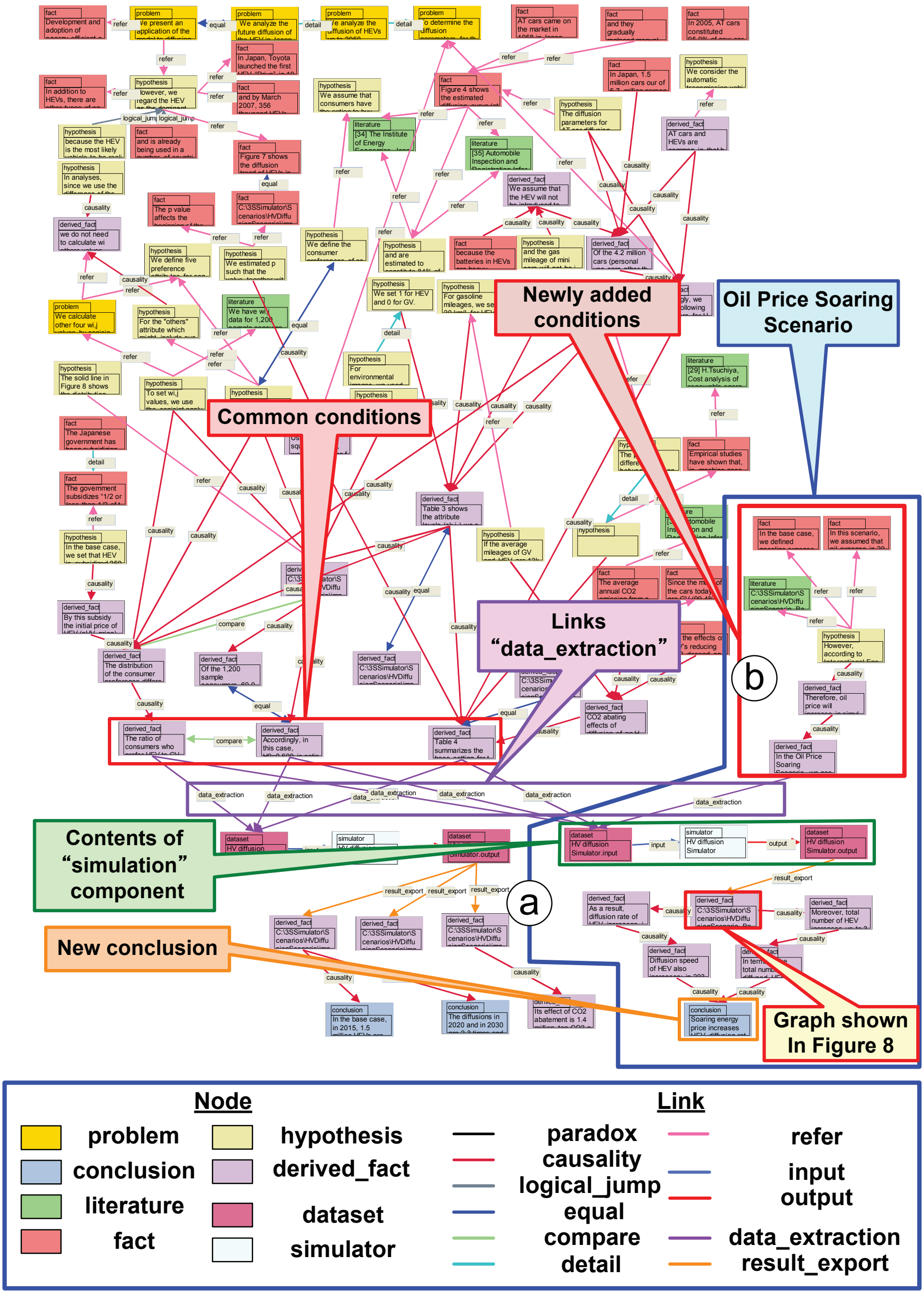

Figure 7. Newly added nodes and links in “Oil Price Soaring Scenario”

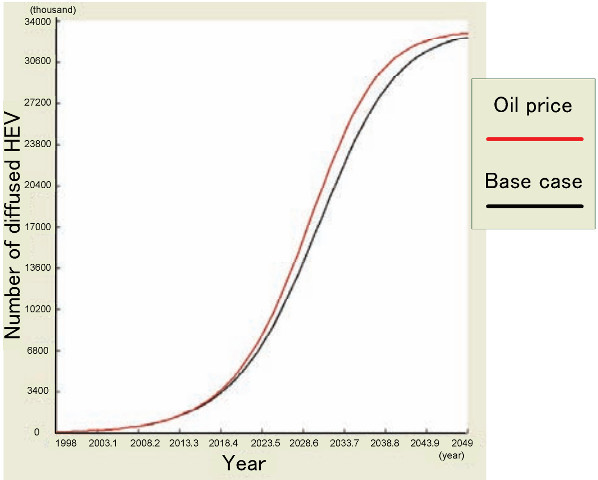

Figure 8. The result of simulation

6 DISCUSSION

With Scenario Visualization Tool, the proposed method enables us to understand scenarios in Scenario, Expression, and Data Levels. In Scenario Level, we succeeded in describing the hierarchical structure of scenarios. Scenario Level also represents the rough structure of storyline; namely, setting the common conditions at first, decomposing into individual sub scenarios, and completing the scenario as a whole based on its sub scenarios. By using Expression and Data Levels, we succeeded in clarifying the flow of a sub scenario is composed in detail in each sub scenario, setting hypotheses, executing simulation, and deriving the conclusions from simulation results. Figure 6**Error! Reference source not found.** clearly represents the causality of this process. "Data_extraction" links clarify the clauses in which input parameters of the simulation are decided. Furthermore, by using this structural information in Figure 6, we could easily make a new sub scenario named "Oil Price Soaring Scenario" from the "base case." The structural scenario description method and Scenario Description Support System proposed in this paper helps scenario authors to describe a number of sub scenarios easily. As shown the case study in Section 5, scenario authors can easily add new hypotheses to an original sub scenario and change values of parameters for new simulation in describing a new sub scenario.

Proposed ontology and modification method can be applied not only for HEV Diffusion Scenario and simulator, but also for any scenario and its simulators. Scenario writers can improve the effectiveness of their scenario, if they write their scenario in proposed method and open their scenarios and simulators to the public.

7 CONCLUSION

In order to realize a scenario design methodology toward the sustainable society, this paper proposed a method to connect scenarios with their simulators in reusable manner. We defined ontology of scenario as an interface between scenario documents and simulators and constructed a scenario modification method by reusing existing scenarios and their simulators. Based on this methodology, we developed Simulator Database and Data Manager in Scenario Description Support System. In the case study, we succeeded in connecting a scenario with its simulator in a reusable manner and in describing a new sub scenario by reusing existing scenario and simulator.

Future works include the development of Scenario Database and Scenario Analysis Tool to modify and verify scenarios. Scenario Design Support System should be developed to support integrated design of sustainable society scenario. Collecting information about existing simulators is important to extend Simulator Database.

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